NASA Tech Days

FIRST Telescope

May 9, 2001

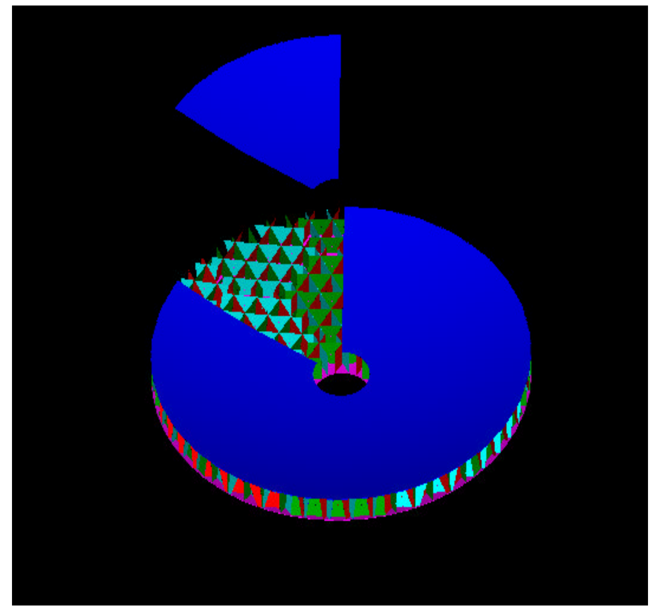
Agenda

- Introduction
- Program History / Why GFRC?
- Design Overview
- Compliance Summary
- 2M Test Summary
- Risk Reduction
- Future Developments

2-Meter Lightweight Mirror Demonstrator and FIRST Telescope Mock-Up

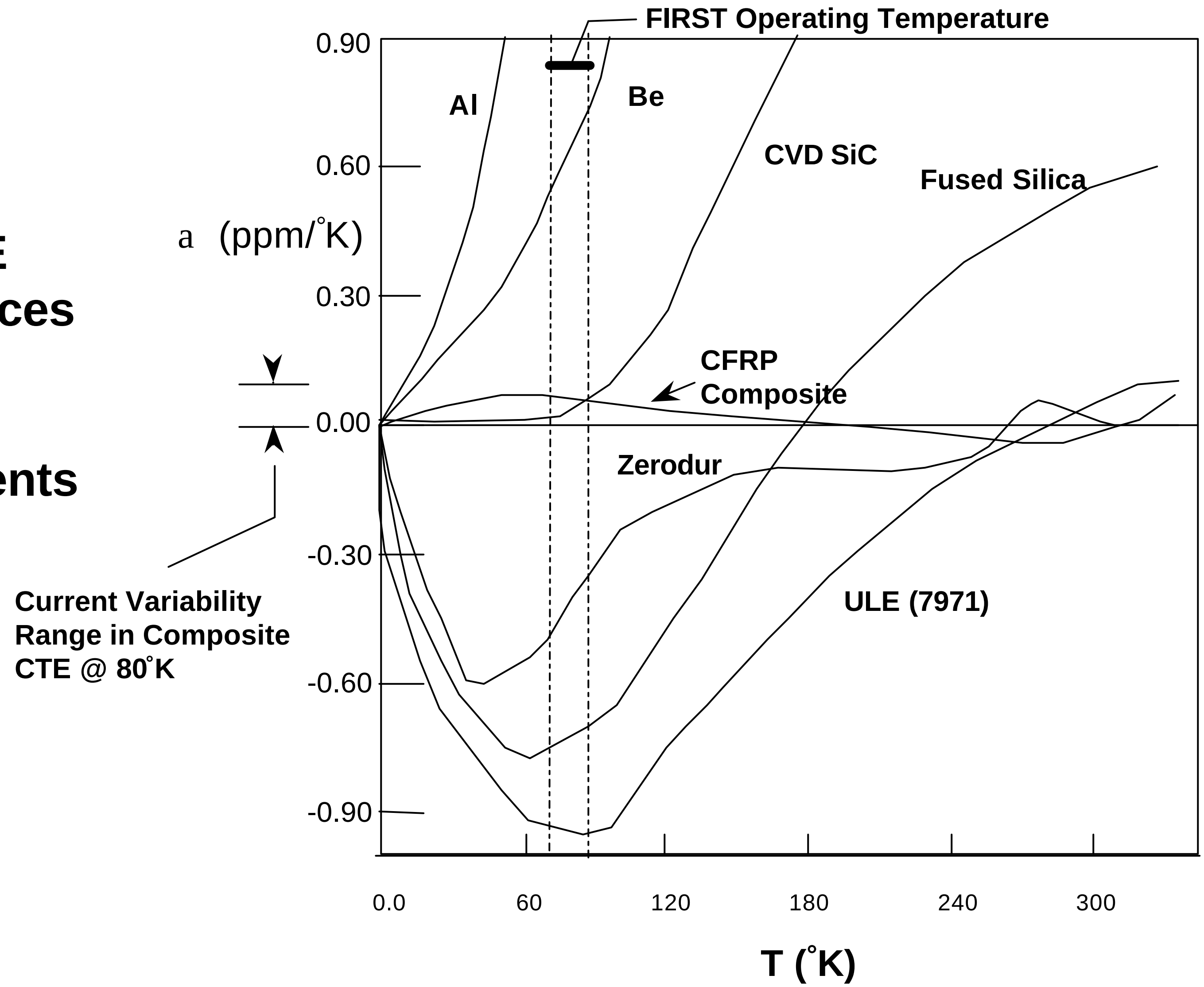
Why GFRP

- **Low Mass - Primary Mirror for FIRST Target Areal Density of 15 Kg/m² (Actual <11)**
- **Low Coefficient of Thermal Expansion (CTE)**
- **Large Cost Reduction When Multiple Mirrors Are Made Off of the Same Mold**
- **Stiffness Is Roughly the Same As Glass and Thermal Conductivity Is Much Higher**

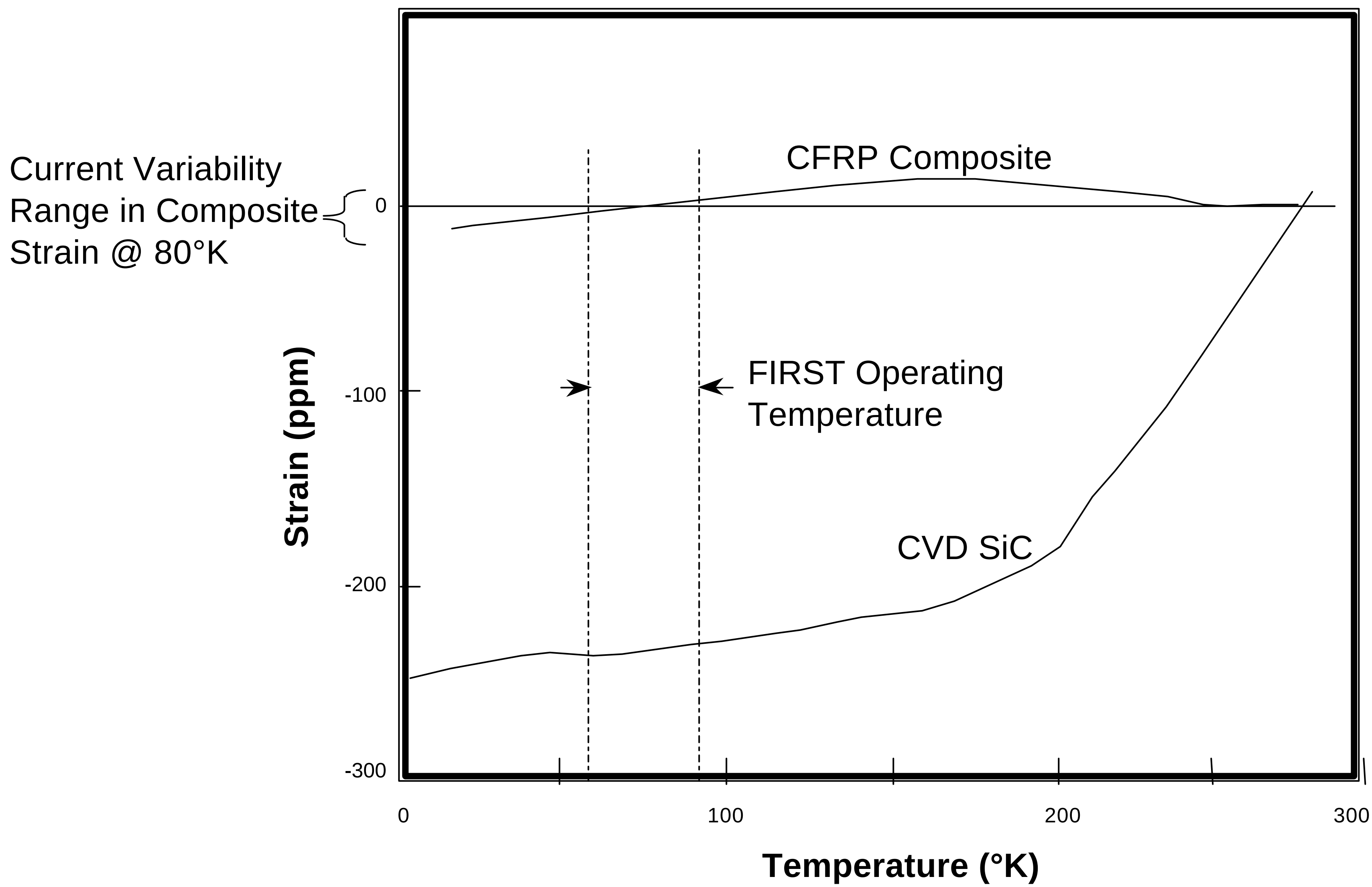


CTE of Selected Mirror Materials

- **Using Low CTE Materials Reduces the Telescope Sensitivity to Thermal Gradients**



Thermal Strains of CFRP Composite and SiC Materials Upon Cool-Down



GFRP Mirror Development Background

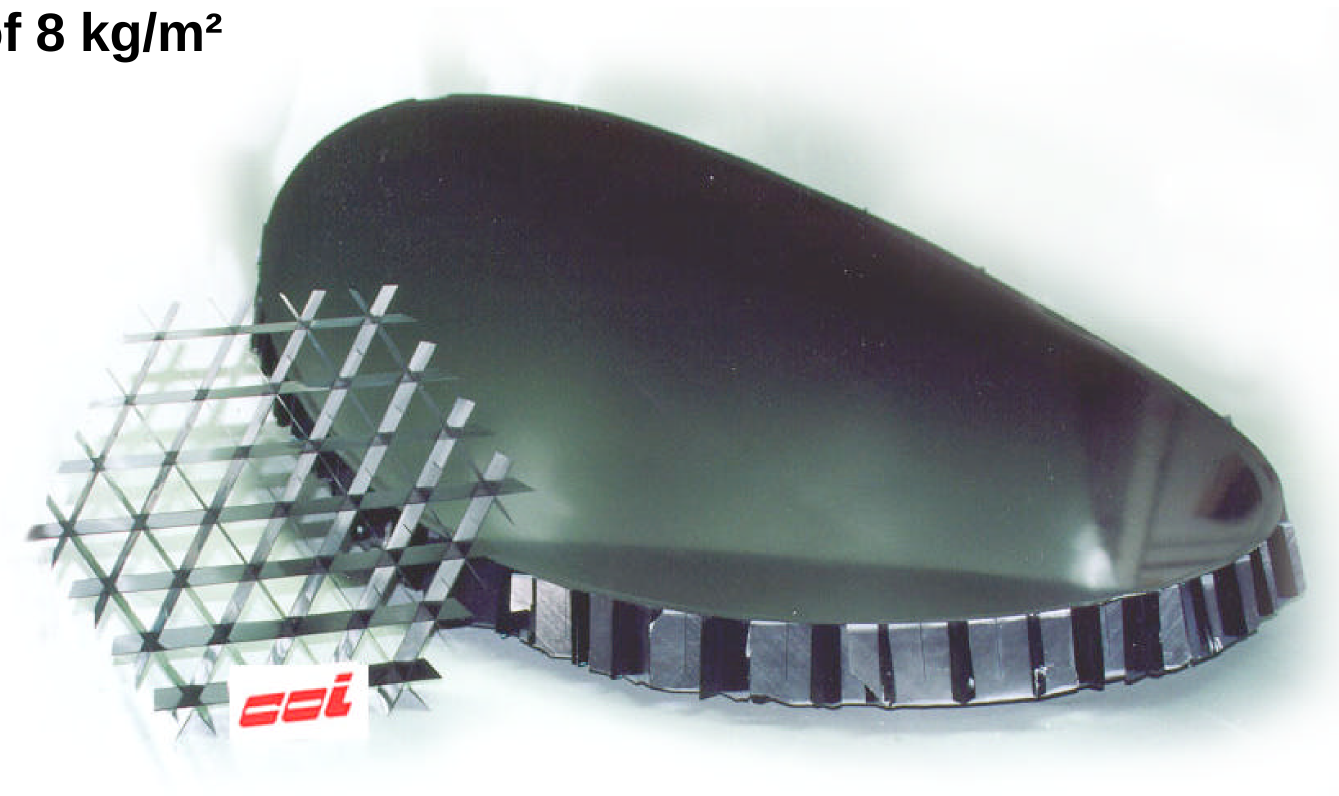
- **GFRP Was Recommended for the 10 to 20m Segmented Large Deployable Reflector (LDR) in the Late ‘80s Because of the Low Mass and the Ability to Economically Reproduce Several Segments with One Mold**
- **The Precision Segmented Reflector (PSR) Program (‘88 - ‘92) Was Funded by NASA to Develop Technology Needed for LDR**
- **JPL Worked with Hexcel to Develop GFRP Mirrors for PSR**
- **Towards the End of the PSR Program JPL Evaluated COI Mirrors**
- **Following the PSR Program GFRP Mirror Development Continued at COI with IRAD and SBIR Funds**

MSFC SBIR Mirrors

Two New Core Designs Reduced the Surface Error Increase with a 100°C Drop in Temperature to Less Than 0.6 μm rms

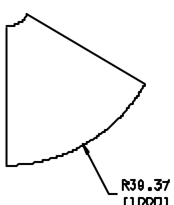
Microwave Limb Sounder Prototype Mirror

- **Surface Error 4.5 μm rms**
- **Result Repeated with Flight Mirror**
- **Areal Density of 8 kg/m²**

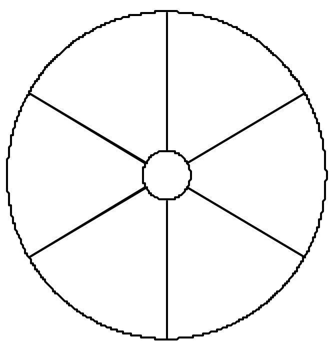


Planned Progression of Mirror Technology Development Hardware

<u>2-m Petal (001)</u>
Preliminary Design
Fab and Cryo Test
Mar-99



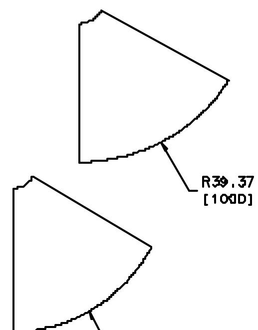
2M PETAL



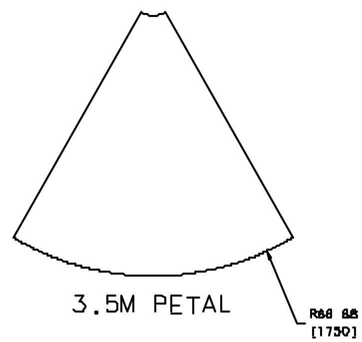
2M ASSEMBLY

<u>2-m Full-Aperture)</u>
Full-Mirror Manufacturing
Fab and Cryo Test
Nov-99

<u>2-m Petal (002, 003)</u>
Design Iterations + Coating
Fab and Cryo Test
Jan-00



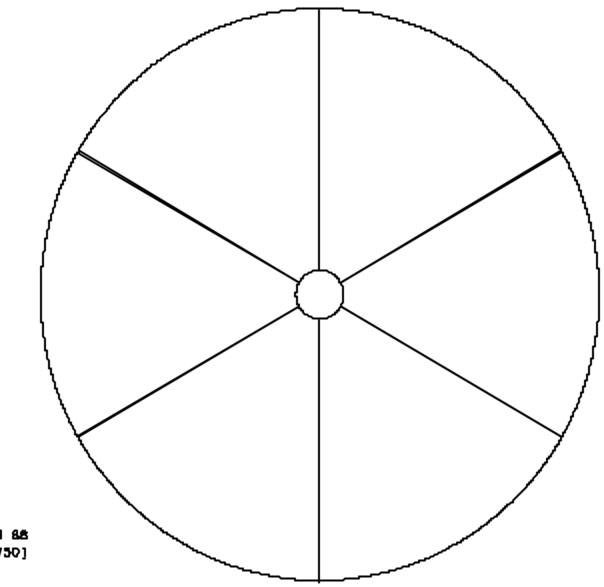
2M PETAL



3.5M PETAL

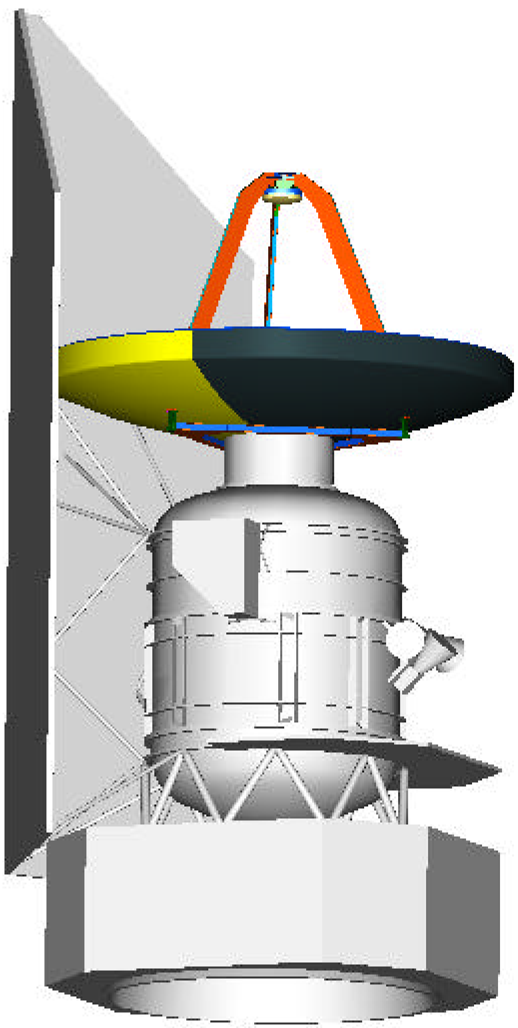
<u>3.5-m Petal</u>
Final Design. Scalability.
Fab and Cryo Test
June-00

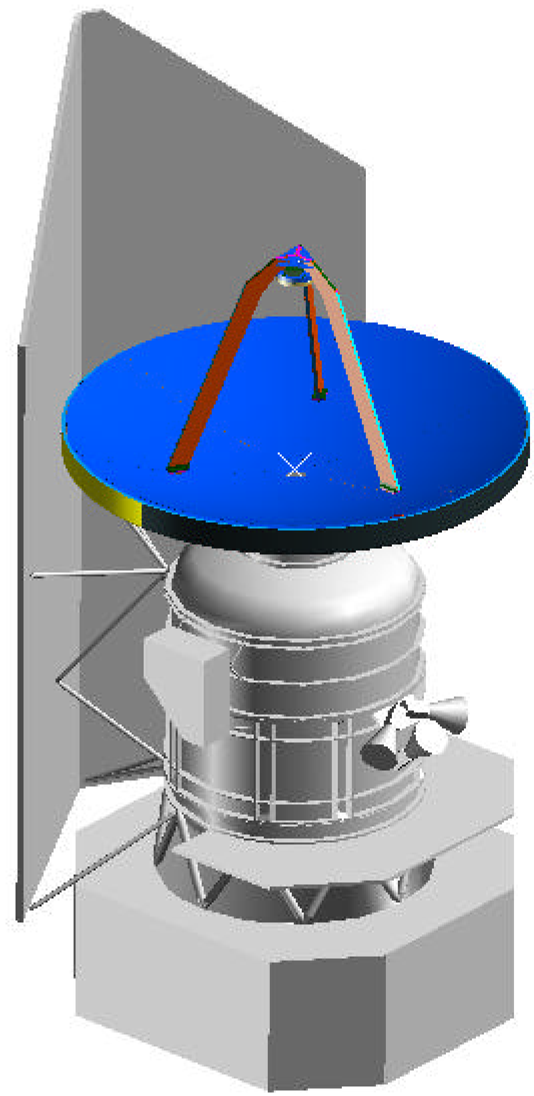
<u>3.5-m Proto-Flight Model</u>
Design & Manuf. Verification.
Fab and Cryo Test
June-04



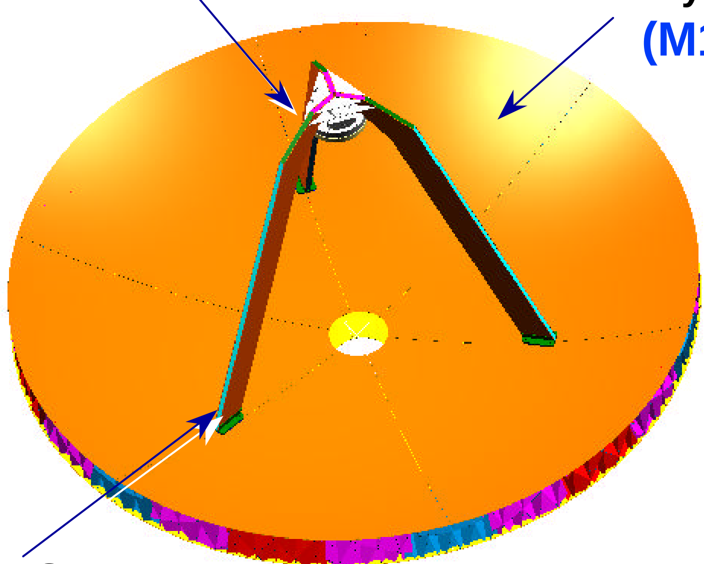
3.5M ASSEMBLY

FIRST Spacecraft

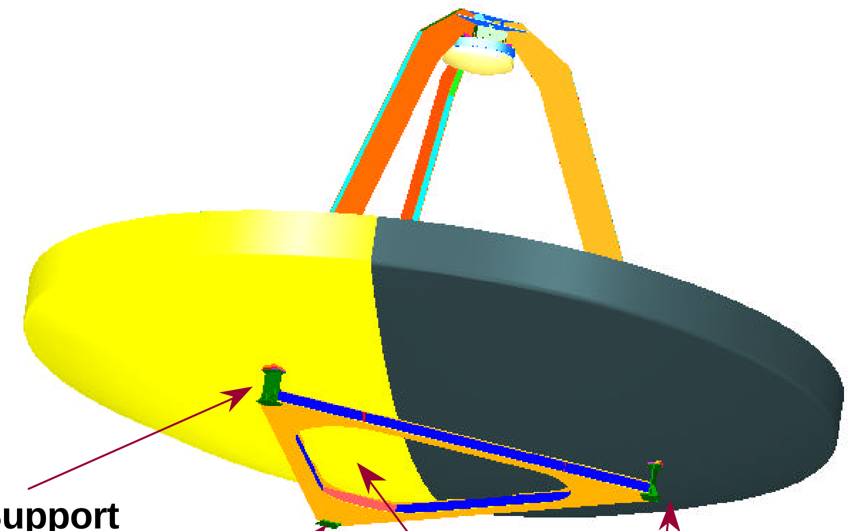




Telescope Configuration

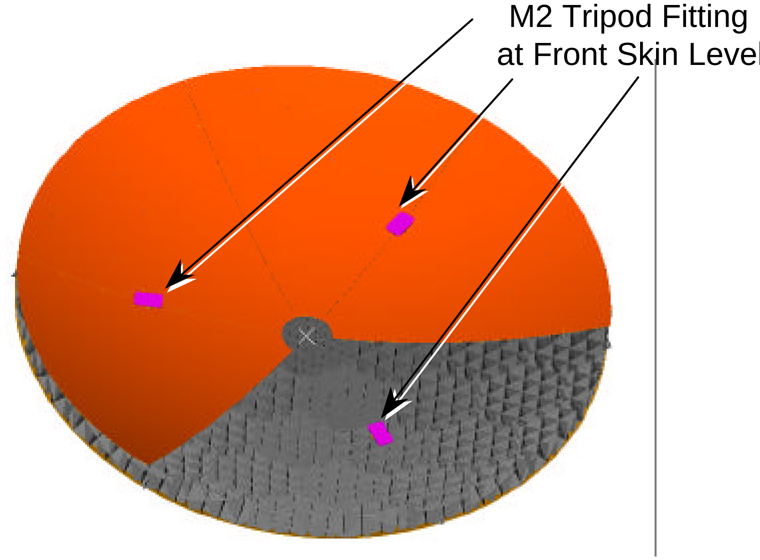


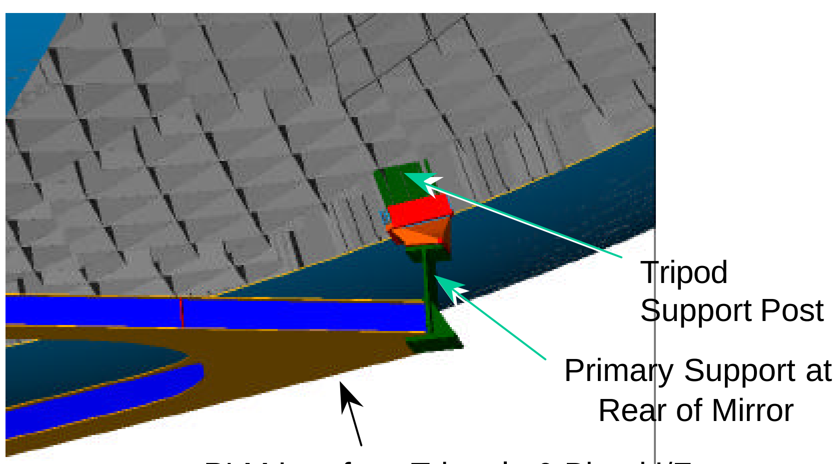
Telescope Mass Breakdown	
Primary Mirror Assembly	141 kg
PLM Interface Triangle	11 kg
Secondary Mirror Assembly	6 kg
Metering Legs	19 kg
TOTAL	177 kg
Requirement	280 kg



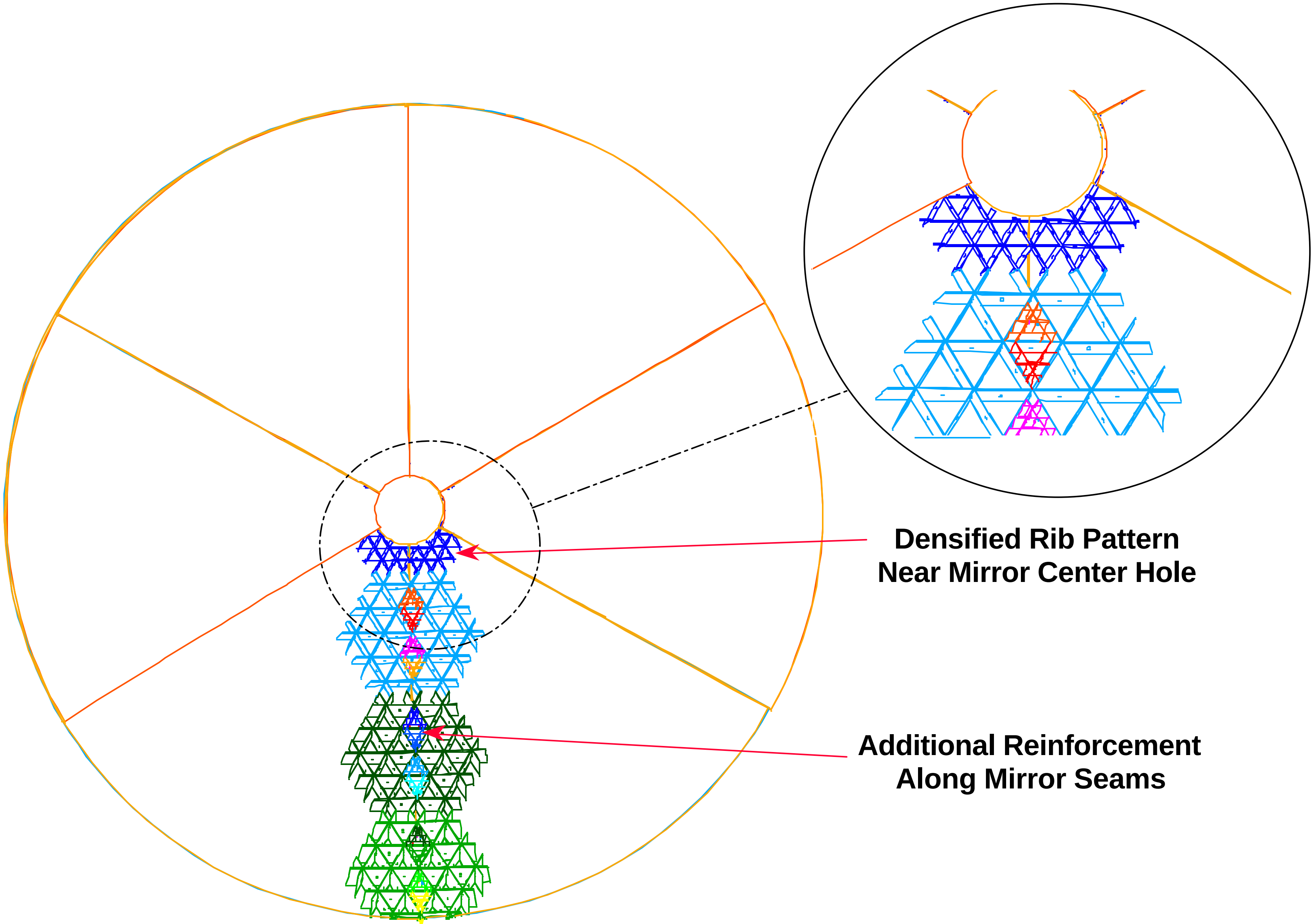
Primary Mirror Design

- **All-Composite, Sandwich Style Design -- Front and Back Faceskin Created from 6 Petal Segments Each -- Core Construction Results in Monolithic Mirror**
- **M55J Carbon Fiber, Cyanate Ester Resin, Epoxy Adhesive Bonds**
- **Invar Fittings Provide Interface to Tripod Attachments and PLM Interface Triangle**





M1 Mirror Design Refinements

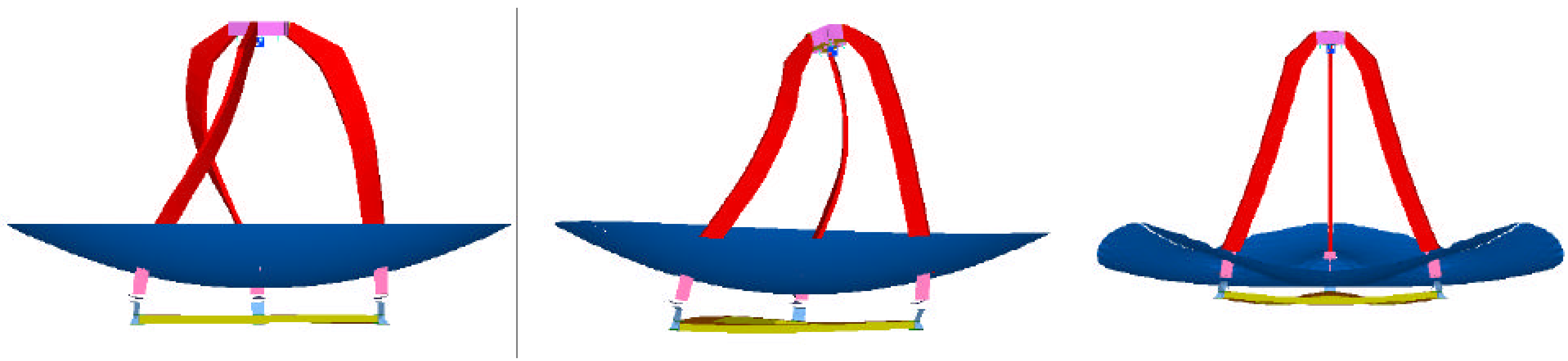


Densified Rib Pattern Near Mirror Center Hole

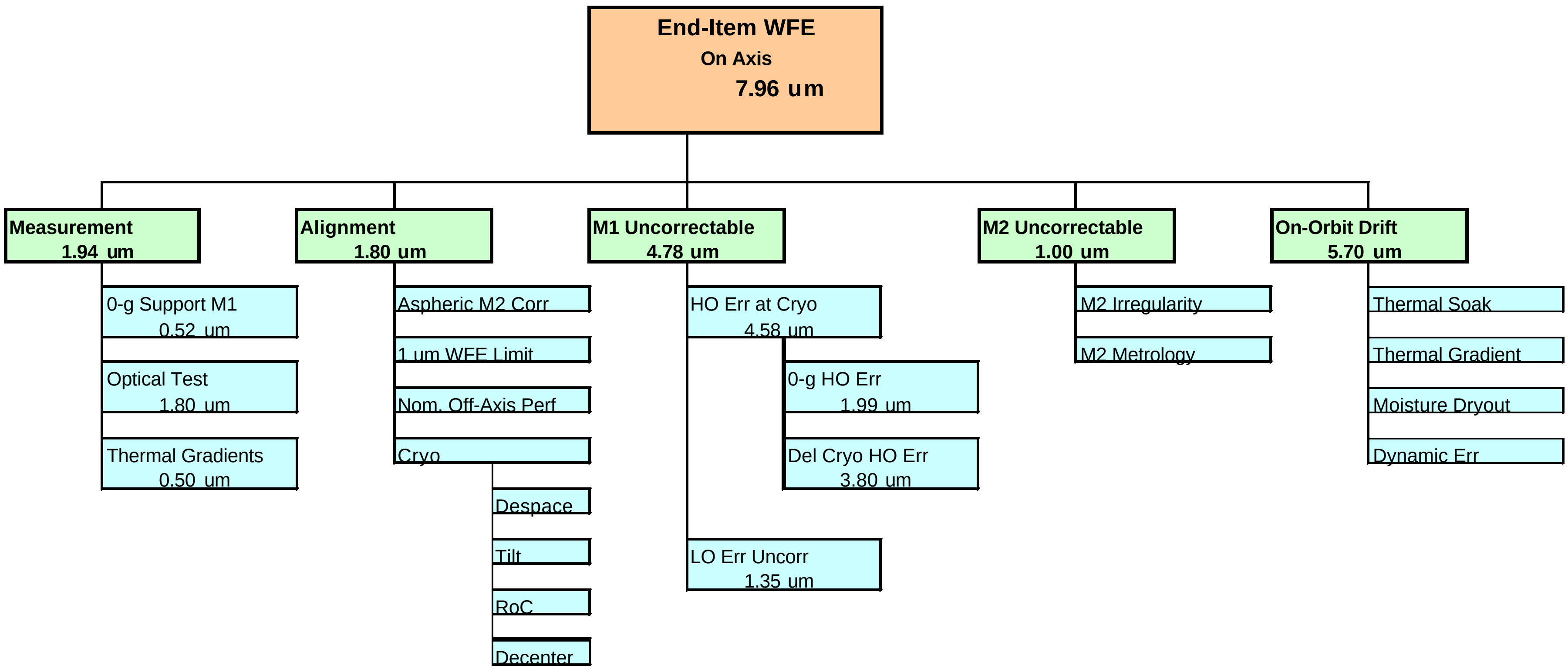
Additional Reinforcement Along Mirror Seams

Structural Compliance Summary

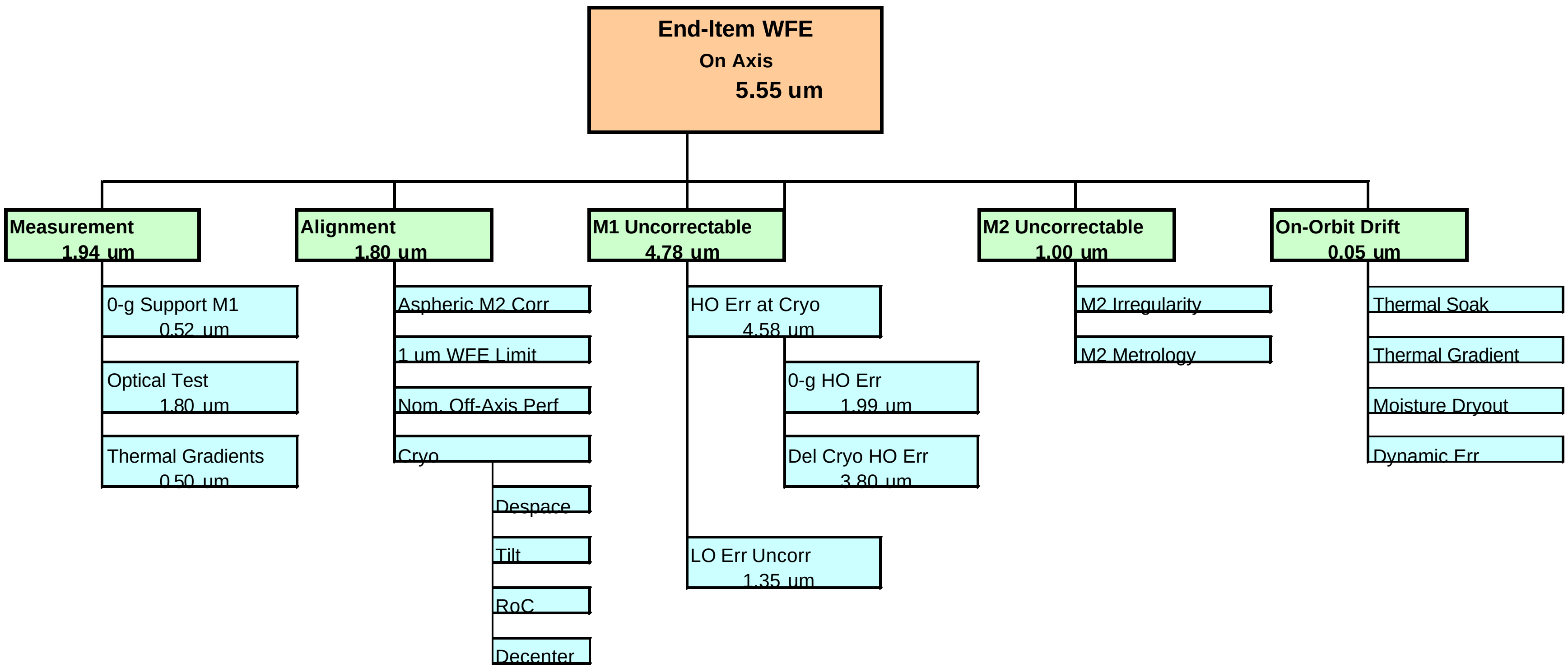
Performance Parameter	Source of Requirement	Required Value	Analysis Prediction	Compliance
Weight	Spec	<280 kg	175 kg	Yes
Stiffness	Spec	> 31 Hz torsion > 45 Hz lateral	52 Hz 53 Hz	Yes Yes
		> 60 Hz axial	138 Hz	Yes
Strength	Spec	Minimum MS ^{3} 0.00	0.02 *	Yes/TBD



Telescope WFE: On-Axis
7.96 μm RMS



Telescope WFE: On-Axis
5.55 mm RMS
with Actuation

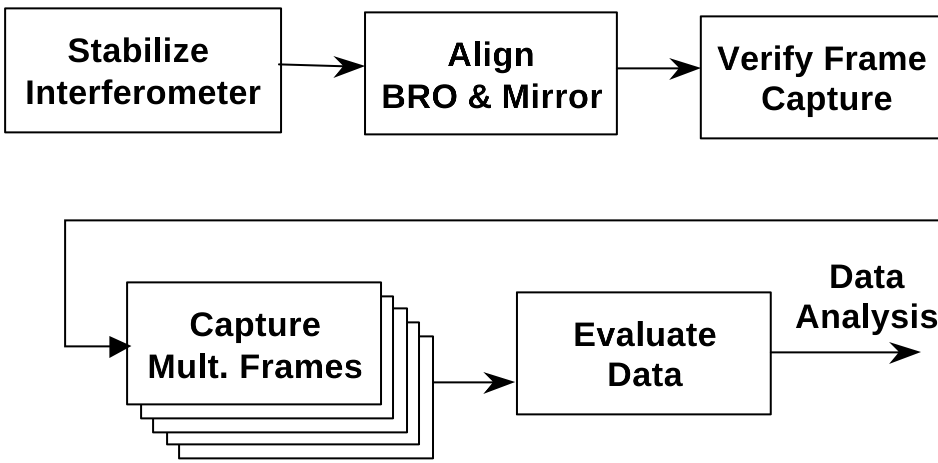


2m Test Results

Scope of the Test

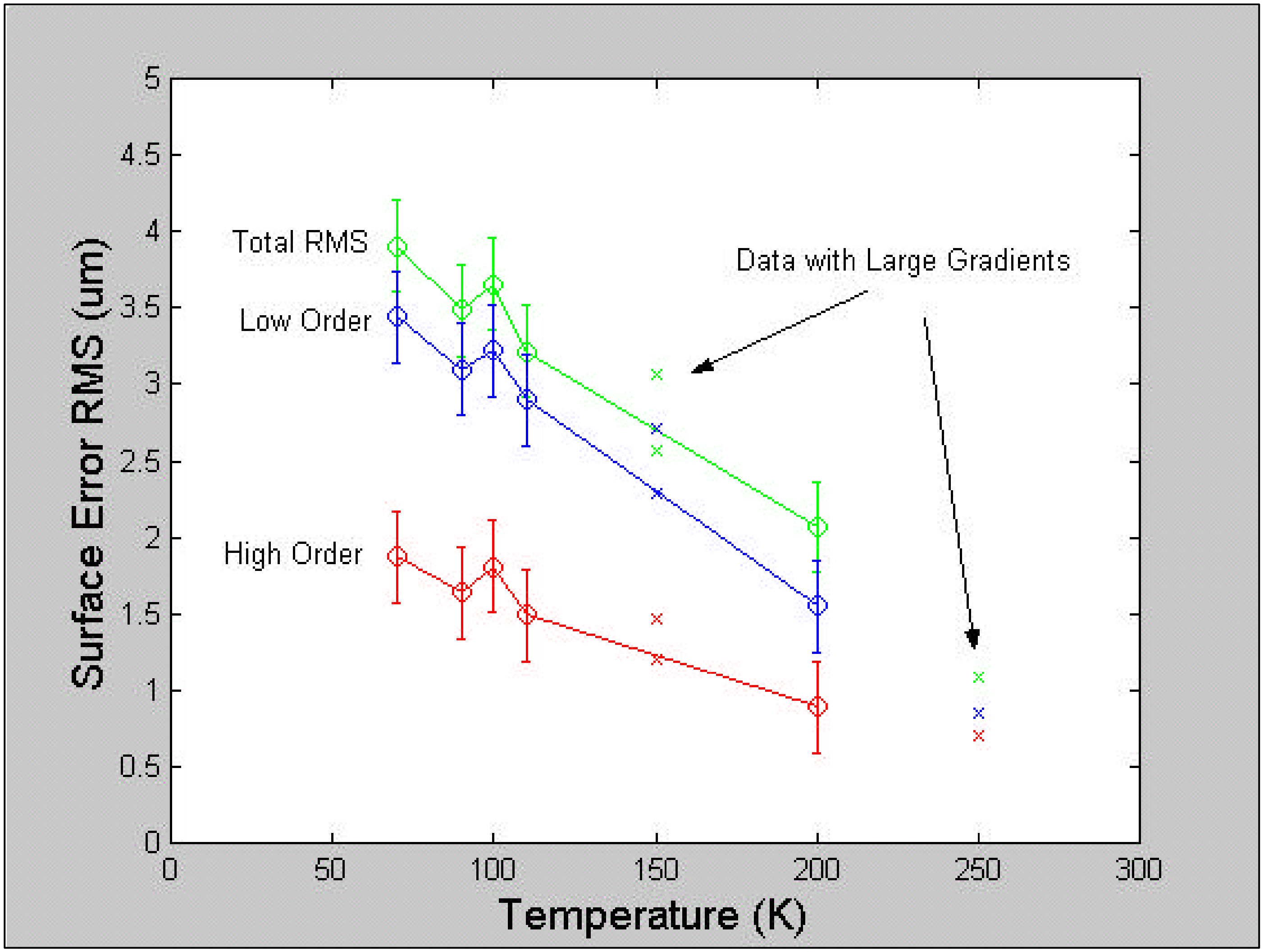
- Measure the Figure of the 2m Mirror at Temperature
- Thermal Cycle to Cold Temperatures
- Induce Thermal Gradients and Understand Effects
- Explore Measurement Methodologies
  - » Sub Aperture Stitching
  - » IR Shack-Hartmann Instrument
- Review of Interferometric Data
  - » Full Aperture
  - » Sub Aperture

Interferometer as Primary Instrument



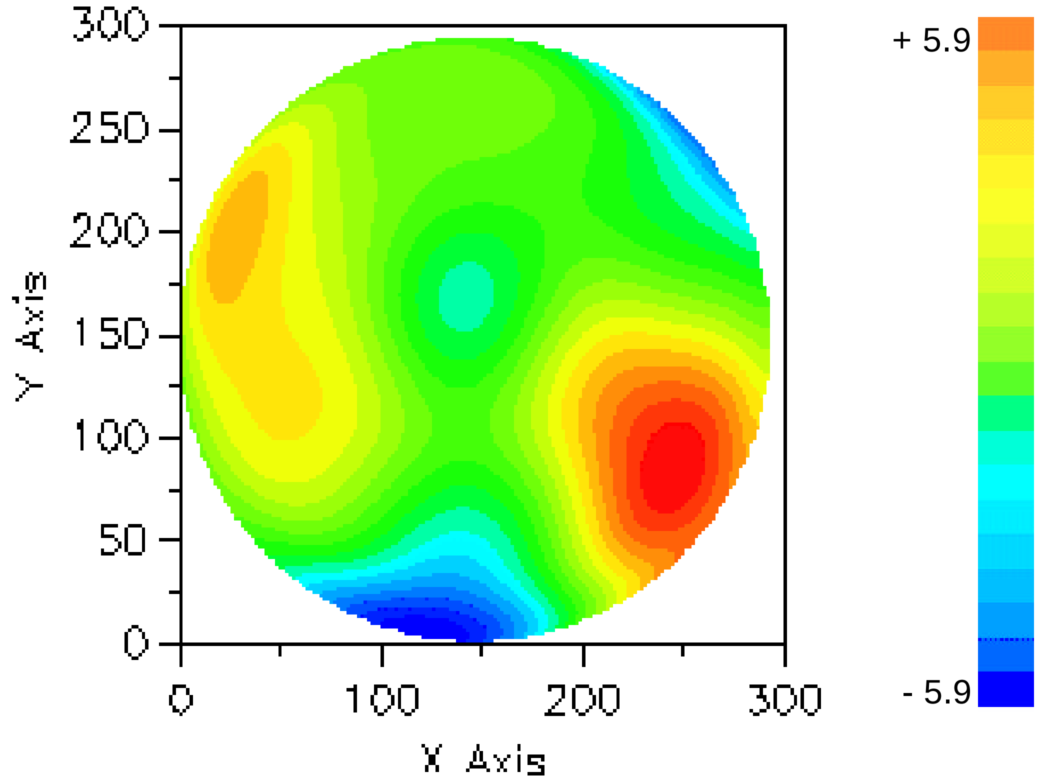
- λ = 10.6 μm (CO_2 Laser) PSI
- Improved Automation - More Objective Data Reduction Criteria

Evolution of Figure vs. Temp



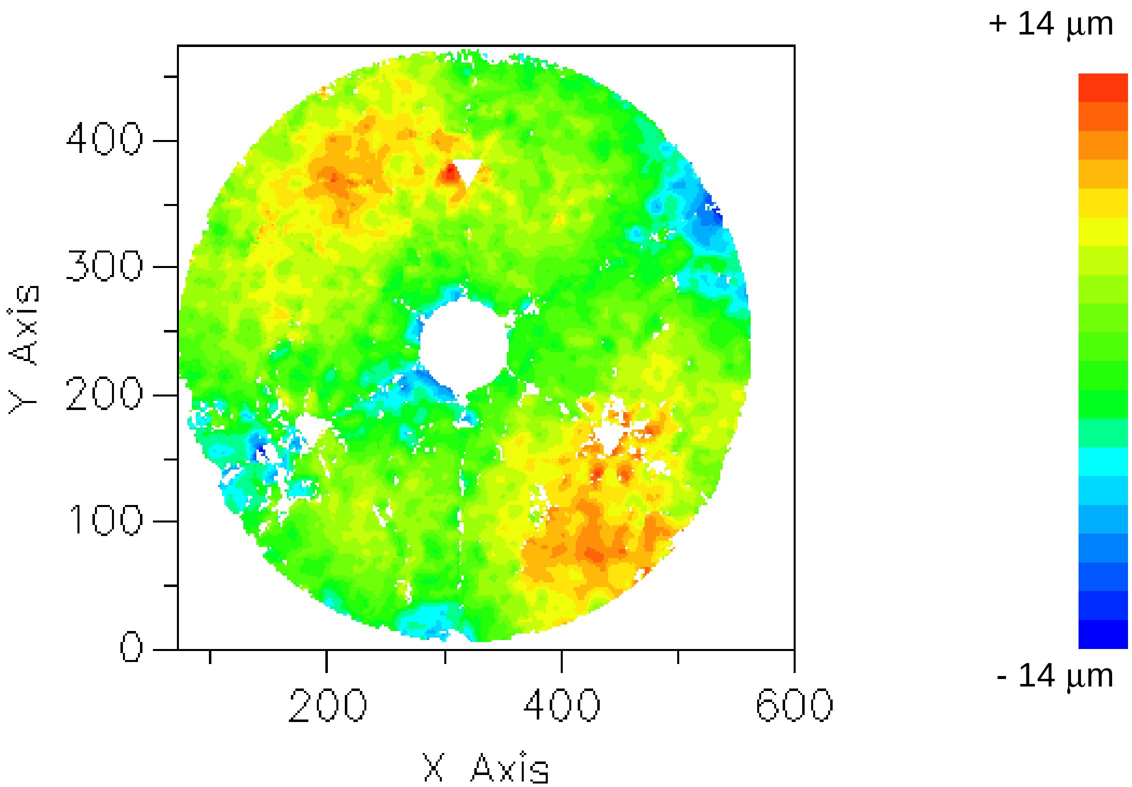
- Modest Variation Over Operating Temperature

Ambient 0 - G: Low Order Figure



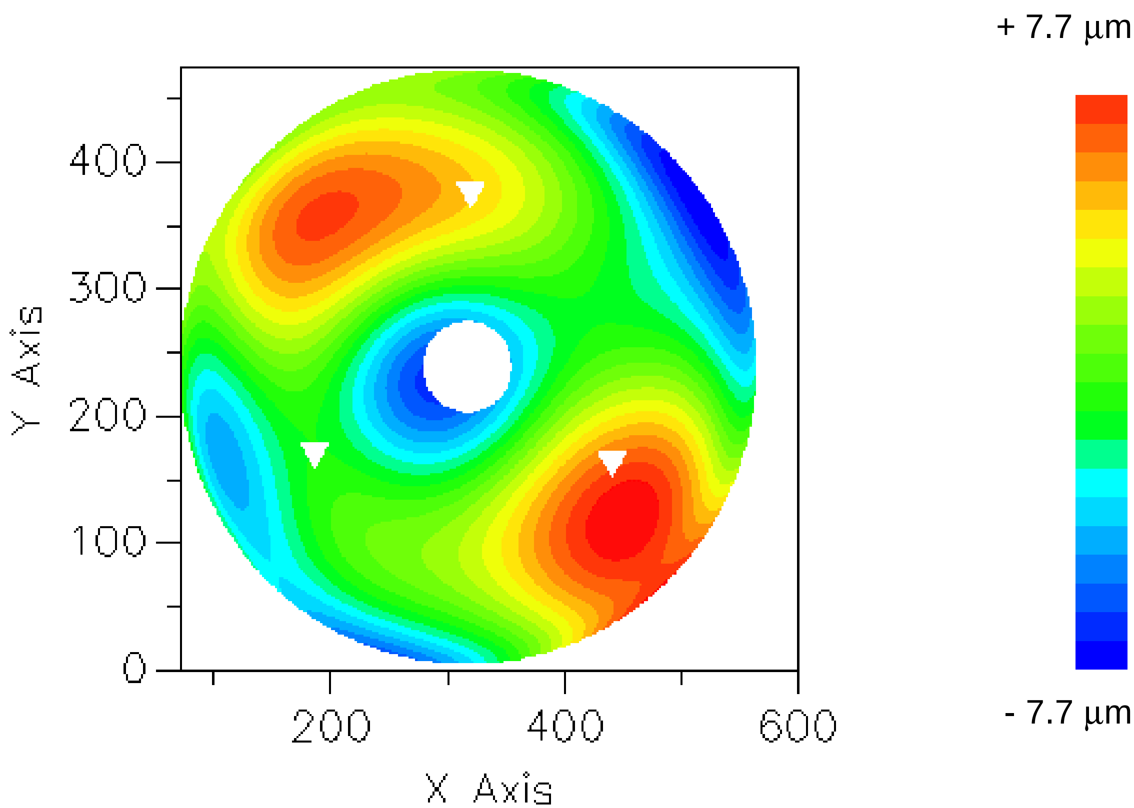
- **Reconstructed Surface Based on Z_5 through Z_{36}**
- **2.11 RMS mm (±0.34 mm)**

Delta Figure: 293K to 70K



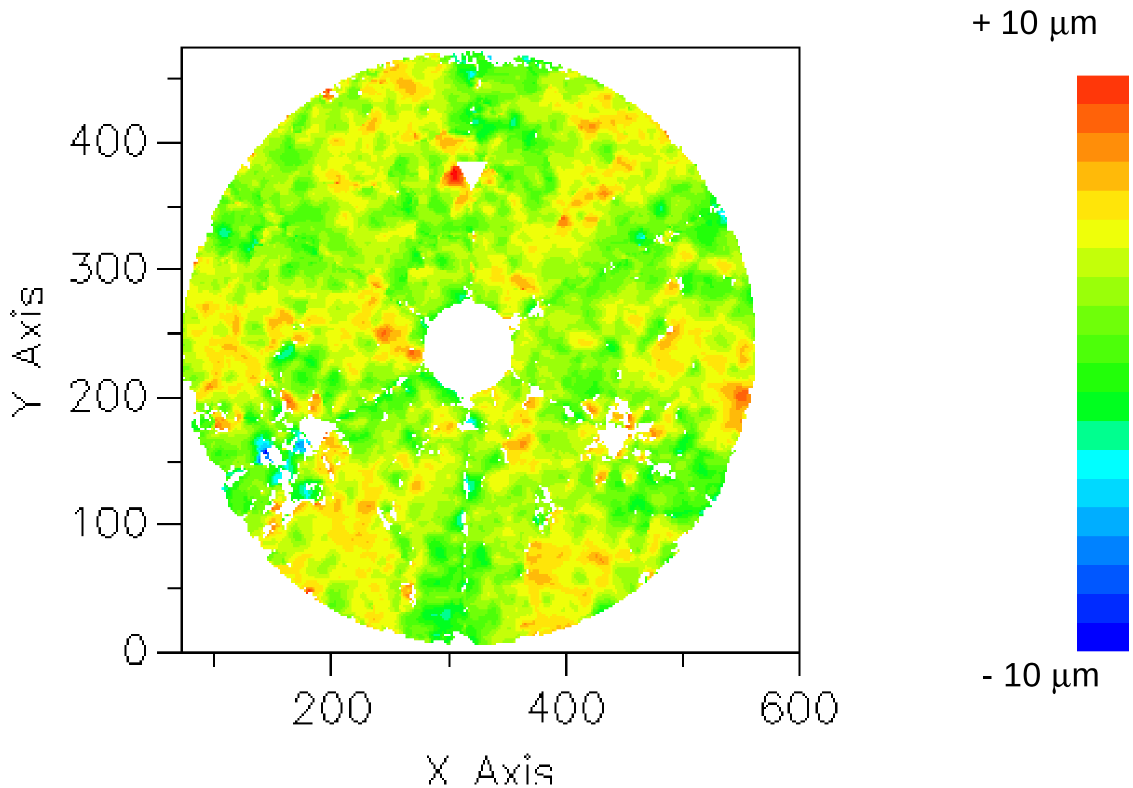
- S_5 - S_2
- **3.9 mm RMS**

Low Order Figure: 293K to 70K



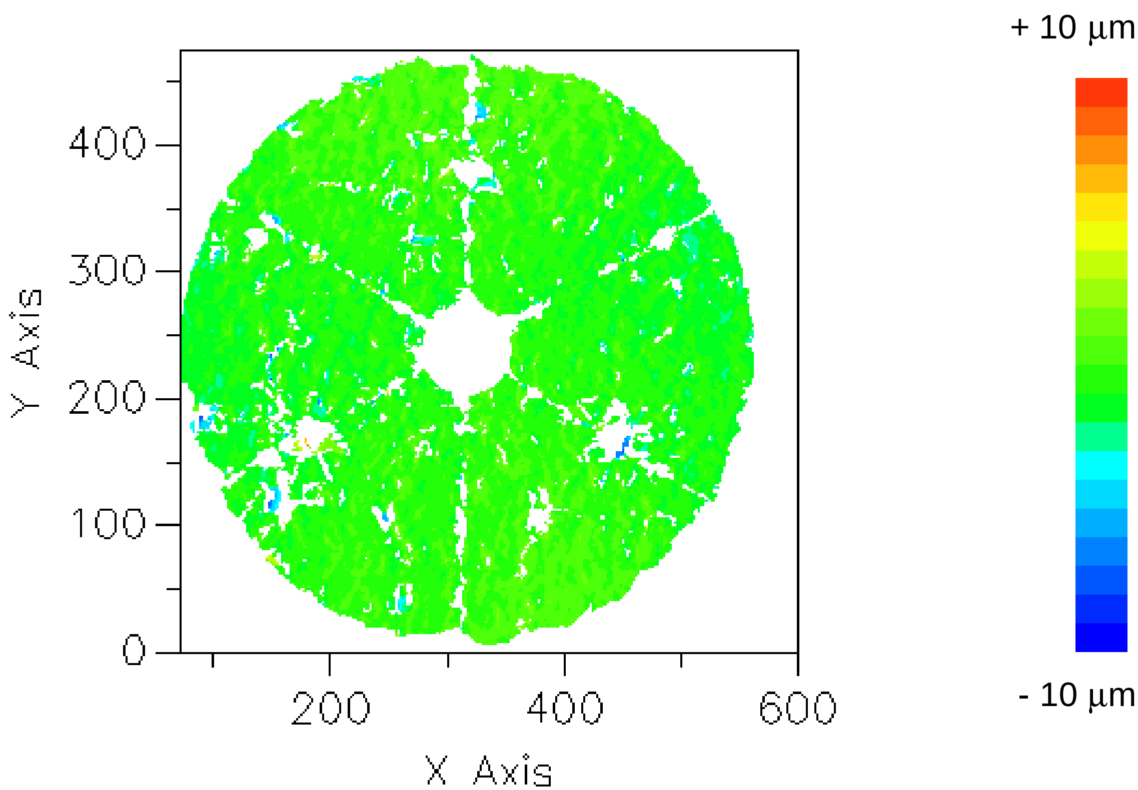
- Z_5 through Z_{36}
- 3.4 mm RMS

High Order Figure: 293K to 70K



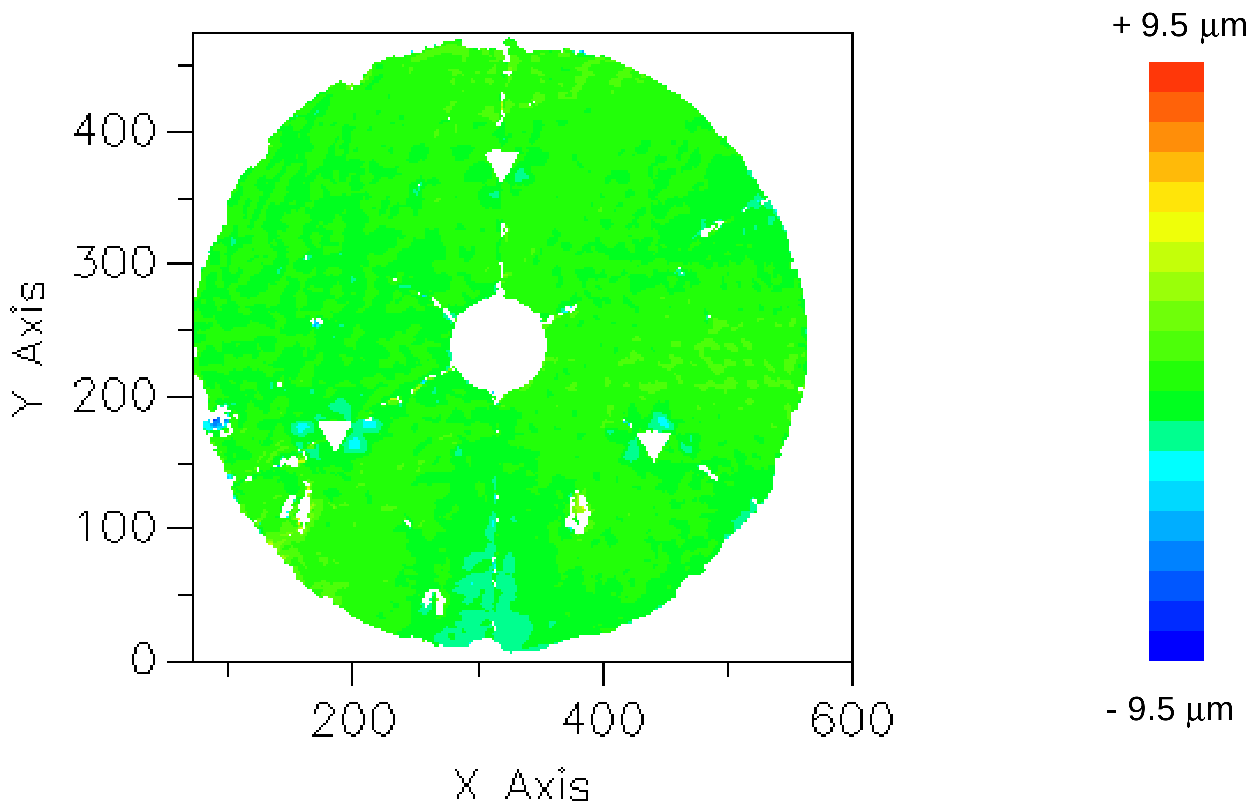
- Residual Figure: > Z_{36}
- 1.9 mm RMS

Hysteresis 70 K



- **Little to No Hysteresis Measurable**
- **0.86 mm RMS**

Hysteresis RT



- **Little to No Hysteresis Measurable**
- **0.55 mm RMS**

Summary

- **Surface Easily Characterized Into Low and High Order Figure**
- **Mirror Has Little Hysteresis**
- **Evolution of Figure vs. Temperature Is Well Behaved**
- **High Resolution Data Collected and Analyzed**
- **Correctability of Low Order Error Has Significant Impact on Final WFE**

Risk Reduction

Preliminary Risk Assessment

- At Beginning of Phase A/B a GFRC Telescope Was Considered a Relatively High Risk Approach
- Risks Were Identified and the Issues Were Worked to Systematically Reduce Risk
- Risks Perceived in Several Categories - Typical Categories Include
  - » Technology Development
  - » Graphite Prepreg Quality and Source of Supply
  - » Process Control of Large Laminates
  - » Intermediate Process Verification
  - » Information Exchange (ITAR)
  - » Cost Control
  - » Coating
  - » Alignment at Cold Temperature
  - » End Item Test Methodology
  - » Metrology
  - » Assembly Fixture
  - » Schedule

Risk Mitigation: Technology Development

- At Beginning of Phase A/B, Risk Was Considered to Be Relatively High as Primary Mirror Performance Dependent Upon Technology Development Yet to Be Performed
- Phase A/B Telescope Development Plan
  - Series of Development Articles
  - Testing of Articles
  - Lessons Learned Incorporated into Subsequent Development Articles
  - Convergence Upon Design Via Combination of Analysis and Test
  - One Development Article Was 2-Meter Spherical Mirror which Was Cryo Tested Optically to 70 Degrees Kelvin
- Currently Risk Is Perceived to Be at Acceptably Low Levels for Primary Mirror

Risk Reduction: Process Control of Large Laminates

- **Process Control and Material Property Verification Drove the Design Change to Segmented Faceskins**
  - » **Smaller Laminates Enable Use of On-Site Autoclave**
  - » **Control Over On-Site Autoclave**
  - » **Minimize Thermal Gradients During Cure with Smaller Laminates**
  - » **Edge Coupons Enable Analytical Predictions Based Upon Material Test Data**
  - » **If Problem During Cure … easier to Scrap One Small Laminate Than Large Laminate**
  - » **Lower Part Handling Risk**
  - » **Include Laminate "Spares" in Plan - Select the Best Laminates for Use in Flight Reflector**

Risk Reduction: Intermediate Process Verification

- **Design Change to Segmented Skins Enabled Intermediate Process Verification**
  - » **Additional Work in Process (WIP) Coupons Around Perimeter of Laminates**
    - **With One Piece Skins Only Perimeter Coupons Available**
  - » **Sacrificial Petal Laminates**
    - **Laminates Cut Into Coupons and Tested**
    - **Gain Insight into Material Property Spatial Variation**
  - » **Process Changes Due to Preliminary Results**
    - **Additional Edge Trim**
    - **Additional Process Homogenization Incorporated**
  - » **Segmented Skins Requires Large Quantity of Coupons to Be Tested**
    - **WIP Testing Schedule Cycle Time Became Schedule Risk Element**
    - **Fabricated Dedicated CTE Chamber to Enable Required Testing Throughput**

Risk Mitigation: Metrology

- **Difficult to Measure the Surface of the Mirror at Cryo Temperatures**
  - » **Slope Errors**
  - » **10.6 Micron Wavelength Instrument Used to Measure Surface for 80-670 Micron Instrument**
- **Improvements Made to 10.6 Micron Interferometer**
- **Improvements in S/N Ratio Via Application of Gold Coating**
- **Metrology Now Considered Adequately Robust for an End Item Optical Test**
- **Mechanical Metrology: Swing Arm Profilometer to Be Delivered with Assembly Fixture**
  - » **Can Measure Convex ASFX as Well as Concave Primary Mirror**
  - » **Intermediate Double Check on Accuracy of ASFX and Mirror**

Risk Mitigation: Coating

- The November 1999 Peer Review Board Considered Coating of a Composite Mirror to Be a Risk Item
- Coating Team Baselined Gold Coating
- Extensive Process Development
- Coated Coupon Testing to Determine Properties
- 2m Mirror Gold Coated with Protective Overcoat
- Other Development Hardware Also Gold Coated
- All Coating Applications Successful
- Technology Risks Retired
- Scenarios to Address Vendor Stability Concerns in Work
  - Similar to Prepreg, COI Personnel Have Been Intimately Involved with Developmental Activity to Date

Technology Chronology

- The Evolution of the NASA Participation in the FIRST Telescope Is a “Poster Child” for NASA
- Technology Development Started with a $25k PSR Contract in 1991
- Initial Success Followed by a Series of SBIRs to Improve Ability to Design, Analyze, Tool, Build and Test Composite Mirror Substrates
- Success of SBIR Led to Selection of GFRC for MLS Flight Primary Mirror
- Success of MLS Mirror Led to Development of GFRC FIRST Primary Mirror
- Success of FIRST Primary Mirror Development Expanded Scope to Include Entire Telescope Effort

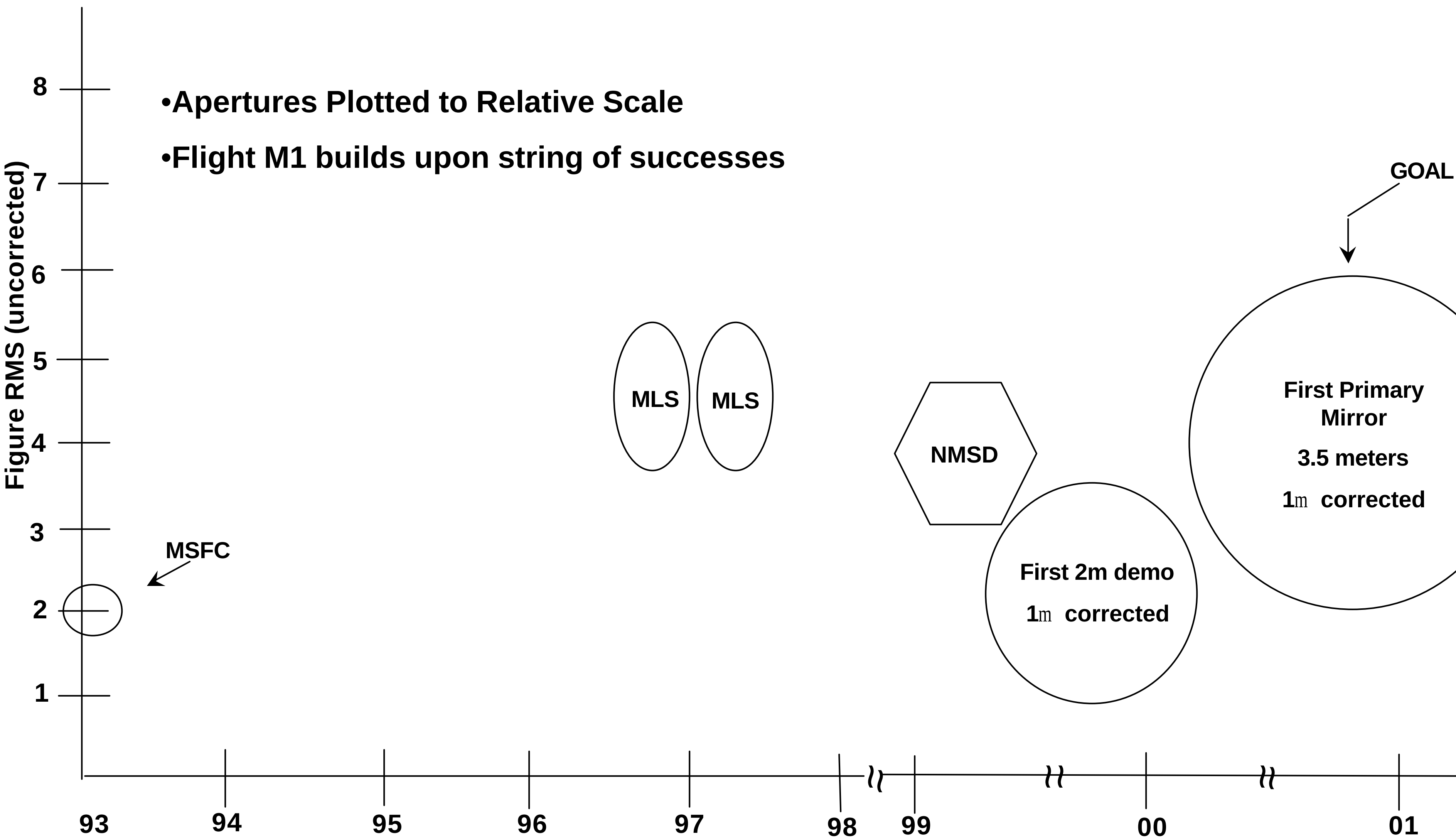
Technology Synergy

- Development Effort for FIRST Telescope Already Benefiting Other Programs
  - » Improved Design Techniques on NGST Structure
  - » Improved Materials and Design on SIM Structure
  - » NPOESS CMIS Reflector
  - » Commercial Ka Band Reflectors
  - » ULE Fusing / Slumping
  - » Metrology Techniques
  - » Fabrication Techniques on LMT

Cost Effectiveness

- **FIRST Telescope Efforts Very Cost Effective**
  - » **Highly Motivated Personnel**
  - » **Schedule Maintained through Phase A/B**
  - » **COI Was Challenged by JPL to Increase Capability and Responded**
    - **Increased Optics Responsibilities**
    - **Increased Systems Responsibilities**
    - **Increased Testing Responsibilities**
  - » **Avoidance of Expenditures on Interesting but Unnecessary Development**
- **Cost per Square Meter of Aperture Must Be an Order of Magnitude(s) less than other Great Observatory/Cornerstone Telescopes**
  - » **\$2.3M/m^2 (Not Including Phase A/B)**
  - » **\$3.5M/m^2 (Including Development)**

Manufactured Mirror Accuracy and Size with Time



Future Directions & Technology Development

- Design Refinements to Improve Cryo-Quilting
- Next-step Improvement in Prepreg Material Quality
- Coatings to Improve Roughness / Mask Fiber Print-Thru
- Polishable Coatings to Reduce WFE
- Imaging Quality Technology Goals
  - » 20 Micron Imaging in 12 Months
  - » 1 – 2 Micron Imaging in 2 – 3 Years
- ULE Reclamation Technology
  - » Reduce Tooling Cost and Acquisition Schedule